Semi-Annual Technical Report No. 1

INTERRELATIONSHIP OF IN-SITU ROCK PROPERTIES, EXCAVATION METHOD AND MUCK CHARACTERISTICS

Sponsored by
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January 12, 1971 - July 31, 1971

HOLMES & NARVER, INC.

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13. ABSTRACT

Reports results of research to correlate the properties of in-situ rocks with materials handling properties of muck from excavation. Goals are to develop methods for predicting muck properties from rock properties and for selection of transport equipment through the Muck Designation Number concept. Muck sample, rock and operating data collection, testing methods, data storage and processing are described.

Results include sample and data collection from eight sites, sample testing by commercial testing laboratories and the PMSRC, and development of raw data-printouts, and narrative-graphic summaries which are included. Samples are classified by operating method, rock strength, and lithology. Program phasing precludes detailed data analysis and conclusions at the present stage. Curves showing muck size distribution vary distinctly with operating methods (Shield, TBM's), rock type (Igneous, Metamorphic, and Sedimentary) and rock strength (High, Medium, Low, and Very Low).

DOD implications include more rational transport equipment selection and design, with resultant speed and cost benefits. Recommended additional research includes Hardness and Abrasiveness tests, sampling operations and formations not currently available, and resampling to improve the confidence level of the data.

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Muck Transportation						

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FOREWORD

This report presents the technical findings and accomplishments of research into the inter-relationship of in-situ rock properties and the characteristics of muck produced by various excavation methods. The period covered is from January 12, 1971 through July 31, 1971.

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INTRODUCTION AND SUMMARY

PURPOSE

The purpose of the program is to develop a method for predicting the materials handling properties of muck from the engineering properties of rock, and a means of selecting the most suitable transportation equipment for muck produced by various excavation systems, through the concept of Muck Designation Numbers.

CONCLUSIONS

Program activities have been confined primarily to data collection and preliminary processing; no definite conclusions can be stated at this time. However, it can be noted from the curves prepared to date that muck size distribution varies distinctly with the rock type and the excavation method.

REFERENCE TO DETAILS

Details of the topics summarized below are arranged under the same headings in the report.

SUMMARY

1. Technical Problems

The importance of increasing the speed of underground excavation while decreasing the cost is emphasized by recent surveys which indicate that a great volume of this work will be required in the near future. Considerable research has been conducted to determine relationships between rock properties and rock drillability, excavation, and support requirements. However, data concerning the characteristics of muck produced by various excavation methods in various rocks are not available for general use in selection or design of muck transport systems. Correlations have not been established between muck characteristics, the properties of the in-situ rock and the components of rapid excavation systems. In the absence of these data, an adequate basis does not exist for optimum selection from the transportation systems in current use, or for development of the high speed systems required in the future.

2. General Methodology

The research plan is to collect muck samples, lithologic and operating data, and rock specimens where necessary, from operating tunnels; determine muck characteristics and rock properties by physical testing; correlate and analyze rock and muck properties, and quantify relationships through Muck Designation Numbers (MDN's); and to correlate rock and muck characteristics, MDN's, and the components of rapid excavation systems with muck transport system capabilities.

Lithologic data consists of descriptions of rocks, their classifications by probable origin and subsequent alteration, and Rock Quality Designations (RQD's) which indicate the frequency of discontinuities. Operating data includes descriptions of the equipment and methods used in the total excavation system. Rock test data includes unconfined uniaxial compressive strength, dry unit weight, and hardness where available. Muck test data includes size distribution and shape, moisture content, and dry loose unit weight.

3. Technical Results

a. Site Selection

A list of current and scheduled tunnels was compiled to assure that program objectives could be met. Sites for data and sample collection were selected with emphasis on mechanical operations in hard rock. Some soft rock and conventional tunnels were included as examples of unusual advance rates and systems. The current list is enclosed as Appendix A.

b. Sample and Data Collection

Initial muck samples and operating data have been collected from eight tunnel sites. A muck sample was taken from a second geologic formation at one site, and additional samples were taken from two sites previously sampled. Lithologic and operating data were collected from one site where no samples were taken.

Rock samples were collected from two geologic formations at each of two tunnel sites, and from one formation at each of five additional sites.

One shield operation, one conventional operation, and six tunnel boring machine sites have been sampled. Rock types include two classified as High Strength, three classified as Medium Strength, one as Low Strength, and two as Very Low Strength. A basis for these classifications follows in the body of the report.

c. Physical Testing

Test procedures were reviewed in detail. Standard tests, approved by the American Society for Testing and Materials, were selected for use by commercial laboratories to insure consistency of results.

Contracts to perform muck tests were negotiated with six commercial laboratories. Samples were delivered for testing and shipment of fractions to the U. S. Bureau of Mines, Pittsburgh Mining and Safety Research Center (PMSRC), for additional tests. At the end of the period, muck tests by commercial laboratories had been reported on seven sets of samples, and on one set by the PMSRC.

Four commercial laboratories under contract were found capable to test rock specimens. Specimens from eight geologic formations were delivered for testing, and one specimen was held pending selection of a laboratory.

d. Data Processing

A format was developed for printout of lithologic, muck, and rock test data; test results received have been stored on punch cards, and printouts of these data are enclosed as Appendix B. A form was developed for narrative and graphic presentation of lithologic, operating, rock and muck test data. Examples are included in the body of the report.

Summaries of rock and muck properties which affect materials handling, and of muck handling system parameters were prepared as guidelines in the development of correlation analysis programs.

Data analysis will follow completion of the major part of the sampling and testing program.

4. DoD Implications

The data accumulated under the program are non-existant elsewhere in rapid excavation technology and will provide a more rational basis for selection of materials handling systems for excavation methods in current use. These data will also be invaluable to the design of the equipment required to match the improved advance rates resulting from current excavation research.

5. Implications for Further Research

The scope of the current program is limited by the availability of time, funds, and work sites in some rock formations of major interest. It is recognized also that the reliability of the data and the resultant conclusions is a function of the sampling frequency. Continuation of the program will improve the confidence level of the data and will provide information on rock types and methods which have not been available for study and analysis.

6. Special Comments

No equipment has been purchased or developed, nor has any invention been made in the course of the work performed under this contract.

1. TECHNICAL PROBLEMS

The effectiveness of planning for new tunnels has been limited by the small quantity of information concerning subsurface conditions which has been available. For many reasons, owners and owner-agencies often have been reluctant to collect data on the properties of materials to be excavated, or to publish information which has been collected. Interested contractors have been forced to base proposals on their own assessments of conditions to be encountered, and to base cost estimates on methods and equipment which may not be well suited for conditions as they exist. Generally, significant allowances are made, both for contingencies which can be anticipated and for those which cannot be foreseen.

The importance of a more logical approach to selection of methods and equipment for tunneling has been emphasized by recent estimates of the great volume of this work probable in the near future, and by the wider application of tunnel boring machines which require rock property data as a basis for design. A trend towards collection and dissemination of more adequate exploratory information for tunnel sites is apparent in the reports of subsurface investigations published by some owner agencies.

Progress has been made and is continuing in research to determine relationships between rock properties, drillability, excavation, and support requirements. Recent investigations have shown, however, that very little information has been collected on the characteristics of the muck produced by the various excavation methods, and that correlations between the engineering properties of rock, muck characteristics, and the components of excavation systems have not been established.

In the absence of muck characteristic data, an adequate basis for selection of optimum transportation methods and equipment does not exist, and tunneling progress and cost have been affected adversely. Muck data are also a basic requirement for engineering the improvements to existing transport systems, and the development of the new systems which will be necessary to keep pace with the higher rates of excavation predicted for the future.

2. GENERAL METHODOLOGY

The objectives of the program are to develop a method for predicting materials handling properties of muck from the in-situ properties of rock, and a means of selecting the most suitable transportation equipment for muck produced by various excavation systems. The major emphasis is on mechanical excavation of hard rock. However, some soft rock and some conventional operations are included as examples of unusual advance rates, equipment, and operating methods.

The program plan is to collect muck samples and operating data from tunnels in rock of known properties; collect specimens from sites where the in-situ properties are unknown; determine muck characteristics and rock properties by physical testing; correlate and analyze rock and muck properties and quantify relationships through the concept of Muck Designation Numbers (MDN's); and to establish correlations between rock and muck characteristics, MDN's, the components of rapid excavation systems, and selection of muck transport equipment.

3. TECHNICAL RESULTS

SITE SELECTION

A list of operating and scheduled tunnels was prepared originally to assure that program objectives could be met. This list has been revised to incorporate changes and additions, and is included as Appendix A to this report. Of the on-continent tunnels, all but one of the nine conventional sites listed are scheduled for continued operation, but two of the fourteen machine operations are no longer available, and two others are scheduled for completion in September, 1971.

An original reluctance of tunnel contractors and mine management to approve site access has been overcome at all but one site. Operators, although under no obligation to participate in the program, have become cooperative when convinced that sampling and data collection are scheduled on a noninterference basis, with full observance of mining and tunnel safety requirements.

Letter inquiries inviting program participation by off-continent tunnel operators have met with no response.

SAMPLE AND DATA COLLECTION

Initial muck samples and operating data have been collected from eight tunnel sites. A muck sample was taken from a new geologic formation at one site, and additional samples were taken from two sites previously sampled. Additional samples usually can be collected in less time than that necessary for initial sampling. In some cases, they provide data on the effect of changes in operation or in geologic formations. In others, they improve the reliability of the data previously collected.

Geologic and operating data were collected at one site where sampling has been postponed until the headings advance into more competent and representative formations.

The scope of collecting in-situ rock data has been greater than was anticipated, because of the nondisclosure policies of some owners and agencies and because formations encountered in some locations could not be correlated with the existing rock data. Rock specimens have been collected for engineering property tests from two geologic formations at each of two tunnel sites, and from one formation at each of five additional sites.

One shield operation, one conventional operation, and six tunnel boring machine sites have been sampled to date. Rock types include two classified as High Strength, three classified as Medium Strength, one as Low Strength, and two as Very Low Strength, based on uniaxial compressive strengths of more than 16,000 psi, 8000 to 16,000 psi, 4000 to 8000 psi, and less than 4000 psi. Other compressive strength tests remain to be reported. One tunnel site has been closed indefinitely following a disastrous explosion and fire. A second site is no longer available as a result of a management decision to remove the boring machine. Muck and rock samples from both sites have been collected and tested. Proposed field work at two sites has been postponed indefinitely because of boring machine modifications.

PHYSICAL TESTING

Test methods were studied in detail to ensure that tests performed by commercial laboratories would yield consistent results. The following American Society for Testing and Materials (ASTM) standard methods were selected as specifications:

C566-67:	Total Moisture Content by Drying
C136-67:	Sieve or Screen Analysis of Fine and Coarse Aggregates
C117-69:	Materials Finer than No. 200 Sieve in Mineral Aggregates by Washing
C29-69:	Unit Weight of Aggregate, Loose Weight Determination
C170-50:	Compressive Strength of Natural Building Stone.

Specifications for the last test procedure have been modified to provide for greater accuracy in specimen preparation so that results will be comparable to those reported by other rock property research programs.

Contracts to perform muck tests have been negotiated with six commercial testing laboratories. Collected samples were delivered for testing and shipment of minus two inch fractions to the U. S. Bureau of Mines, Pittsburgh Mining and Safety Research Center (PMSRC) for additional tests to be performed at this facility. At the end of the reporting period, muck tests by commercial laboratories had been reported on seven sets of samples, and on one set by the PMSRC.

Four commercial testing laboratories under contract were found capable to test rock specimens. Specimens from eight geologic formations have been delivered to these laboratories, and one specimen is held pending selection of a laboratory.

Methods of testing abrasiveness were also reviewed to determine the feasibility of collecting these data from tests on muck samples. The standard ASTM tests were found to measure the resistance of the sample to abrasion, rather than the abrasive effect on other materials. The latter is the property of greater interest in materials handling. Fractions of all muck samples are being retained for possible tests for this property, pending selection of an appropriate test procedure.

Results of hardness tests by the Shore scleroscope, a laboratory instrument which tests hardness by rebound of a hammer, are available for only one of the rock formations sampled. Additional tests by this method were found to be beyond the scope of this study. Hardness testing by the Schmidt hammer, a portable device which also tests rebound hardness, is described as nondestructive and relatively inexpensive. Rock specimens are also being retained for possible future tests by this method.

DATA PROCESSING

A summary of rock and muck properties which affect materials handling, the range of the values of muck and rock properties which will be available, and the parameters of muck handling systems was prepared as a guideline in the development of correlation and analysis programs. Current planning is in general conformity with the methods described in Appendix C to the "Engineering Classification and Index Properties for Intact Rock", D. U. Deere, et al., University of Illinois, 1966.

A format was developed for computer printout of lithologic, muck and rock test data. Test results received to date have been stored on punch cards. Printouts incorporating these raw data are included as Appendix B to this report. Narrative and graphic summaries of lithologic, operating, rock, and commercial muck test data are shown in the following figures numbered 1 through 13. Rock strength classifications used in these summaries are based on uniaxial compressive strength, and conform with those proposed by D. U. Deere, et al, in the "Engineering Classification and Index Properties for Intact Rock", referenced above. These classifications are:

Very High Strength	-	Greater than 32,000 psi.
High Strength	-	16,000-32,000 psi.

Medium Strength - 8,000-16,000 psi.

Low Strength - 4,000-8,000 psi.

Very Low Strength - Less than 4000 psi.

Grain size classifications of igneous rocks, from A. Johannsen's "A Descriptive Petrology of Igneous Rocks", 1931, are used as follows:

Very Coarse - above 3 cm

Coarse - 1 to 3 cm

Medium - 1 to 10 mm

Fine - below 1 mm

From J. F. Kemp's "A Handbook of Rocks", 1950, sedimentary rocks of fragmental grains above 2 mm, are classified as conglomerates, while those below 2 mm in size are classified as sandstones or siltstones.

Symbols used to describe the shape of particles in the sample fractions between screen sizes are the following:

A - Angular S - Sub-Angular

P - Platy R - Rounded

E - Elongated C - Cubic

I - Irregular Sp - Spheroid

The curves show the percentage of the total sample weight passing one screen size and retained on the next. The six inch screen is included primarily to show the percentage of the muck which would require crushing for transportation systems capable of handling only minus six inch material. Screen sizes below 1/2" were selected to provide openings which become progressively smaller by approximately fifty percent, as shown below:

Screen Size	#4	#8	#16	#30	#50	#100	#200
Nominal Square Openings, Inches	0.187	0.094	0.047	0.023	0.012	0.006	0.003

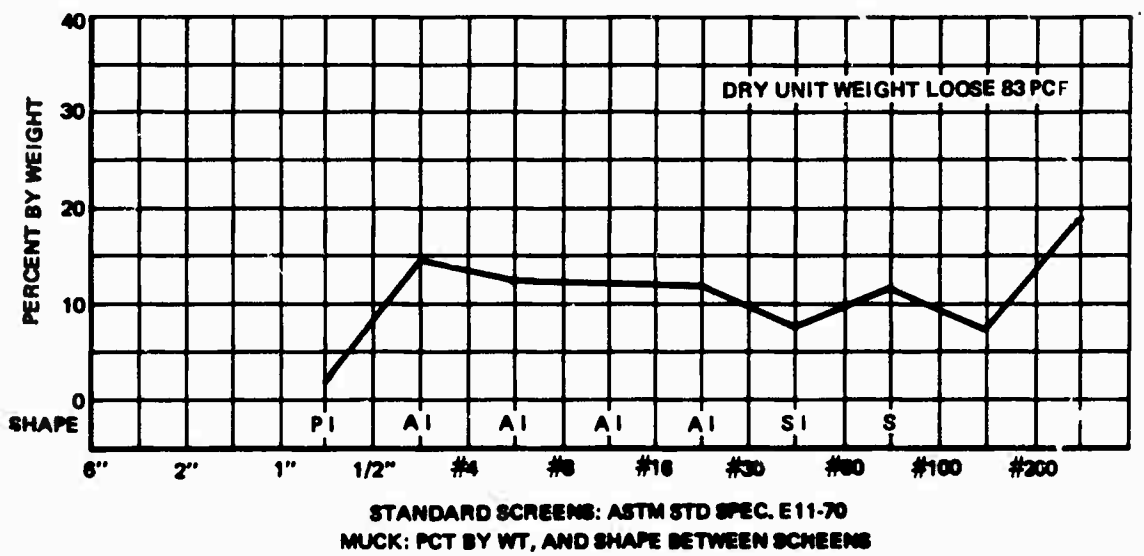
The abbreviation "N. A." is used to indicate that data is not available on the date of the report. A similar graphic presentation is being considered for data from the PMSRC laboratory.

Program activities have been confined primarily to data collection and preliminary processing: no definite conclusions have been reached. However, distinct variations in particle size distribution with variations in formation and cutter type can be noted from the curves prepared to date. These variations would appear to provide a basis for assignment of MDN's if additional data confirms the initial trend.

ROCK DATA: Lithology: Igneous: Gray medium to fine grained granite moderately to slightly fractured and jointed, 10 to 20 percent Quartz, 50 to 60 percent feldspar, balance dark minerals. Uniaxial Compressive Strength: 18 K psi. Estimated RQD: 90 percent. Dry unit weight 167 pcf. Ground water occurrence: minor, primarily from fault zones.

TUNNEL DATA: Size: 9'9", Shape: round, Grade (+) 0.22 percent, Ventilation System: 22" pipe, 10 K cfm, exhaust. Utility System: 6" air line, 2" water line, 6" pumpline. Water inflow 5 to 20 gpm. Power system: 4160v/480/240120v. Haulage system: Muck, personnel, supplies by cars, 36" gage, 70# rail. Support system: 4" ring and half sets, at 4', 3' and 2' centers in bad ground, 16 gage plates secured by 4-1" x 7' grouted bolts, normal ground.

EXCAVATION DATA: Machine: Make: Wirth Erkelenz, Hardrock Model Tungsten carbide button cutters, total number-25: Gage 6-11 1/2" TCB roller, interior 15-11 1/2" TCB roller, center 2-11 1/2" roller, 2-11 1/2" TCB Cone. Torque: 600 HP, RPM Head: 8 to 11, Total Thrust: 500 K lbs., Maximum Anchor pressure: N.A., Muck system: bucket from face 22" belt conveyor to rear. Guidance system: Laser. Power System: electric motor driven hydraulic pumps driving hydraulic motors.



Rock Class: Igneous: Medium to fine grained granite. High Strength. RQD 90 percent. Dry unit wt 167 pcf.

System Class: Machine, TCB roller and cone, Rail Haulage.

IDENT. NUMBER NAST-1

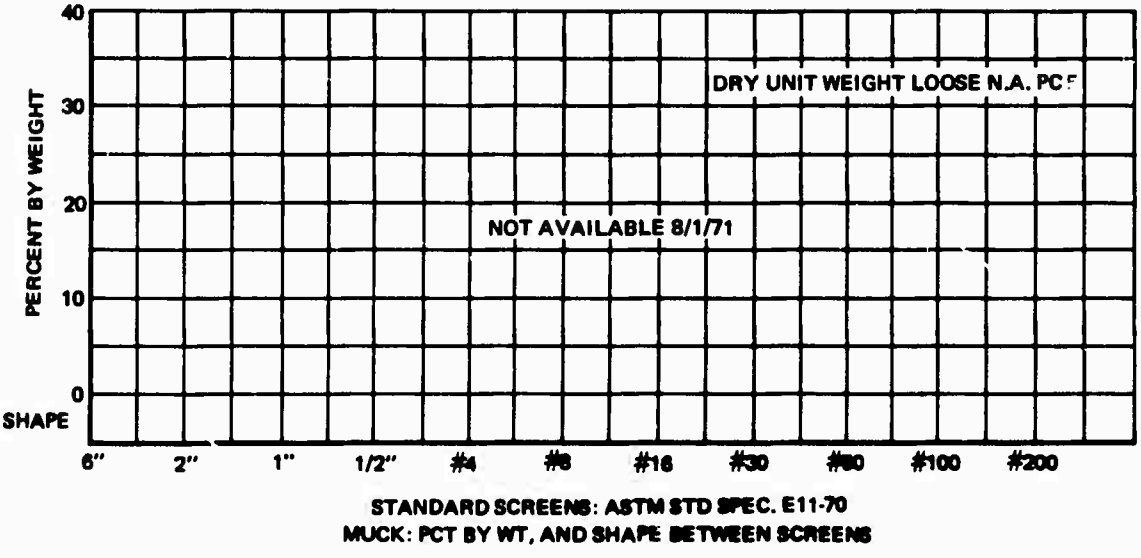
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-1

ROCK DATA: Lithology: Igneous: Gray medium to fine grained granite moderately to slightly fractured and jointed, 10 to 20 percent Quartz, 50 to 60 percent feldspar, balance dark minerals, Uniaxial Compressive Strength: 18 K psi. Estimated RQD: 90 percent. Dry unit weight 167 pcf. Ground water occurrence: minor, primarily from fault zones.

TUNNEL DATA: Size: 9'9", Shape: round, Grade (+) 0.22 percent. Ventilation System: 22" pipe, 10 K cfm, exhaust. Utility System: 6" air line, 2" waterline, 6" pumpline. Water inflow 5 to 20 gpm. Power System: 4160V/480/240/120V. Haulage system: muck, personnel supplies by cars, 36" gage 70# rail. Support system 4" ring and half sets, at 4', 3' and 2' centers in bad ground; 16 gage plates secured by 4-1" x 7' grouted bolts, normal ground.

EXCAVATION DATA: Machine; Make: Wirth Erkelenz, Hardrock Model Tungsten carbide button cutters, total number-25: Gage 6-11 1/2" TCB roller, interior 15-11 1/2" TCB roller, center 2-11 1/2" roller, 2-11 1/2" TCB Cone. Torque: 600 HP; RPM Head: 8 to 11; Total Thrust: 500 K lbs., Maximum Anchor pressure: N.A., Muck system: bucket from face, 22" belt conveyor to rear. Guidance system: Laser. Power System: electric driven hydraulic pumps driving hydraulic motors.



Rock Class: Igneous: Medium to fine grained granite. High Strength. RQD 90 percent. Dry unit wt 167 pcf.

System Class: Machine, TCB roller and cone, Rail Haulage.

IDENT. NUMBER NAST-1

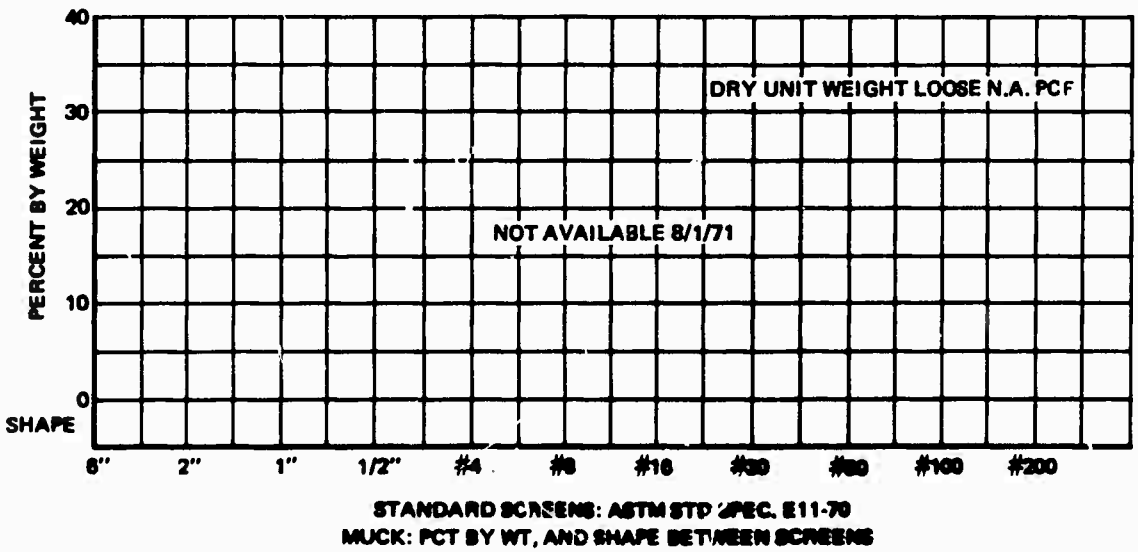
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-2

ROCK DATA: Lithology: Igneous: Fine grained, moderately joined gray granite with 1.5' to 2' bands of light tan pegmatite and laminated granitic gneiss. Uniaxial compressive strength N.A. K psi. Estimated RQD: 80 percent. Dry unit weight N.A. pcf. Formations generally dry, occasionally seeps through joints.

TUNNEL DATA: Size and Shape: 10' x 10', Modified Horseshoe, Grade: (+) 1/2 percent, Ventilation: Exhaust, 26" dia., 15 KCFM, 125 HP at 7200' from portal. Utility system: 8" Compressed air, 4" water, 10" pump. Water inflow: 10-25 gpm. Power supply: 4160V/480/240. Haulage: All rail, 36" gage, 75#, 3-15T. Goodman locomotives; 2 trains of 5 to 7 cars @ 4.8CY. Canton car transfer at 50' to 250' from face, passing tracks @ 1500'. 4" H bm sets @ 4', 3' and 2' for 23 percent, 1" x 7' grouted bolts for 17 percent. Shotcrete: 500 psi @ 18 hrs., 3750 psi @ 28 days, for 16 percent of 7200'.

EXCAVATION DATA: Rail mounted hydrojib jumbo, 4-CF99, & 1-CF133 drifters, 12' contin. feed. Spiral burn cut, 10 1/2" deep. 1-5" center hole & 37 @ 1 3/4" dia. Explosives: 183 lbs. Gelex #2-75 percent x 1 1/2" dia., and 20 lbs. Smoothtex 70 percent x 7/8" dia. in 12 upper perimeter holes. Reg. delays 0 to 10. Powder factor: 5 1/2 #/CY. Mucking system: EIMCO #25, rail, air operated.



Rock Class: Igneous: Fine grained granite and granitic gneiss interlayered with coarse grained pegmatite. Strength class: N.A. RQD: (estimated) 80 pct. Dry Unit Wt. N.A. pcf.

System Class: Conventional, Rail Haulage.

IDENT. NUMBER H-1

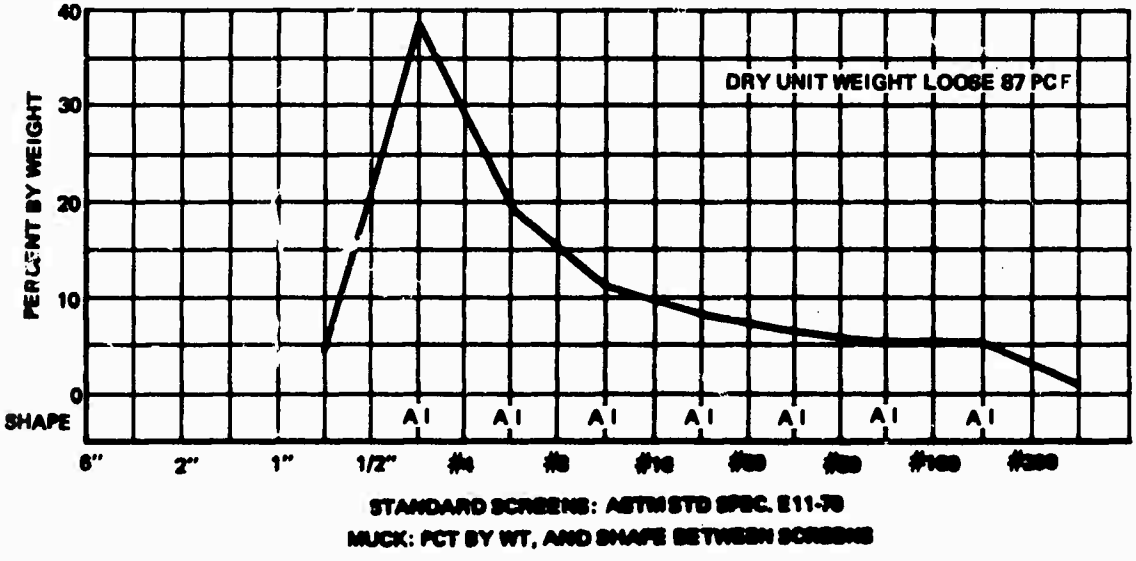
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-3

ROCK DATA: Lithology: metamorphic, highly metamorphosed granitic gneiss, moderately to highly fractured, highly silicified. Uniaxial compressive strength 9.3 K psi. Dry unit weight 174 pcf. RQD 10 percent. Ground water is minimal due to drainage to shafts and other workings.

TUNNEL DATA: Size: 13', shape: round, Grade (+) 1/4 percent. Ventilation system: exhaust 24" pipe 10 K cfm. Utility system: 4" air pipe, 2" waterpipe. Water inflow: 5-10 gpm. Power system: 4160/480V. Haulage System: personnel, muck, supplies by rail. Support system: none required.

EXCAVATION DATA: Machine: make and model: Calweld, Hardrock. Total weight 200 tons. Type and make of cutters: Tungsten carbide button, Smith Tool Co., Total number 19: 1 TCB tricone center, 12 GT-MH8 roller, interior, 6 GT-SH8 roller, gage. Rotation: Center cutter-26 RPM, Head-12 RPM. Total thrust 1,128 K psi. Mucking system: buckets from face 24" conveyor to rear. Power System: Hydraulic. Torque: 100 HP, center; 600 HP, head. Guidance system: Laser.



Rock Class: Metamorphic: Silicified granitic gneiss Medium Strength. RQD 10 percent. Dry Unit Wt. 174 pcf.

System Class: Machine, TCB tricone and rollers, Rail Haulage.

IDENT. NUMBER C1-1

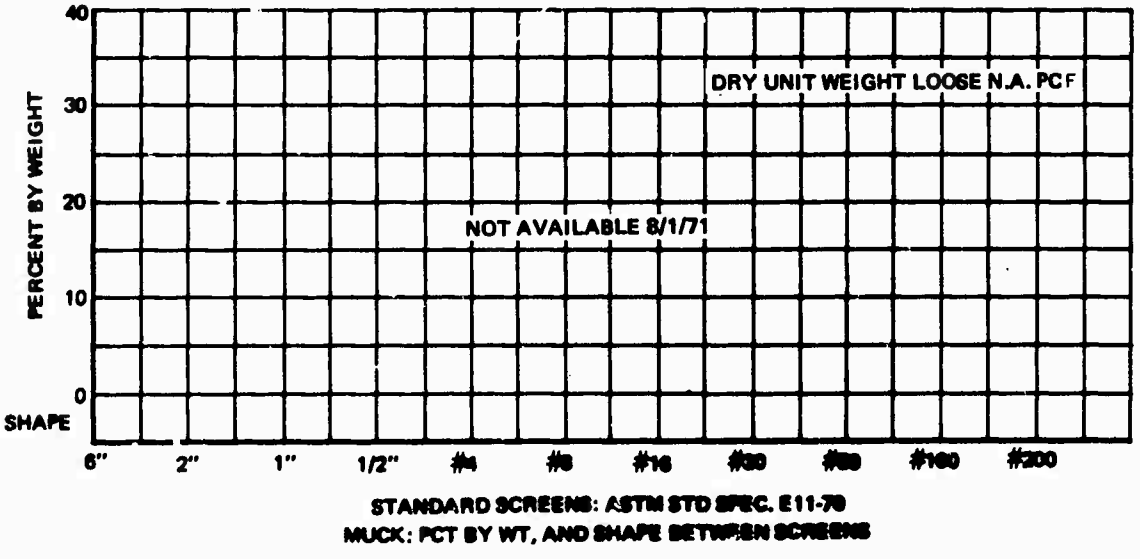
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-4

ROCK DATA: Lithology: Metamorphic: gray mica schists, occasional quartz seams, mica varies from dense fine grained to extremely coarse. Uniaxial compressive strength: N. A. K psi. Estimated RQD 30 percent Dry Unit Wt.: N. A. pcf. Ground water: major inflow occurs in faults and fault zones.

TUNNEL DATA: Size 11', shape: round, Grade (+) 1 to 3 percent. Ventilation system: 14" pipe, exhaust 4K cfm. Utility system: 4" water-pipe, no air. Water inflow 60 gpm, drains in ditch. Power system: 4160V/480V. Haulage system: muck, personnel, supplies by rail. Support system: None, occasional semi-circular plates pinned at spring line in fault zones.

EXCAVATION DATA: Machine: Make and Model: Jarva, Mark 11-1100, Total weight 70 tons, Type and make of cutters: steel multiple disc, Reed: Total number 36: 2 disc center, 26 disc interior, 8 disc Gage, RPM cutter head 10 3/4. Torque, head 244 K ft. lbs. Maximum anchor pressure 3, 402 K lbs. Thrust 1, 134 K lbs. Muck system: buckets from face, belt to rear. Power system: Hydraulic. Guidance System: Laser.



Rock Class: Metamorphic: Fine to very coarse grained mica schist. Strength N. A., RQD 30 percent. Dry Unit Wt. N. A. pcf.
System Class: Machine, Steel Disc, Rail Haulage.

IDENT. NUMBER QL-1

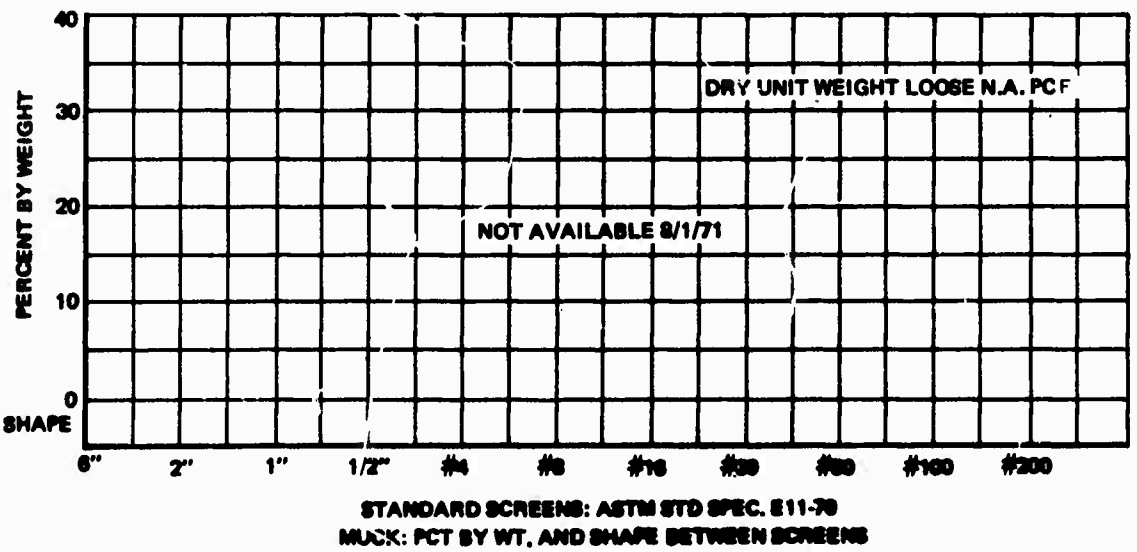
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-5

ROCK DATA: Lithology: Metamorphic: Interlayered bands of hematite and martite, highly jointed, normally flat lying, but often highly folded. Natural iron over 60 percent, moisture 9 percent, silica 5-1/2 percent. Uniaxial compressive strength N.A. K psi. Estimated RQD: 0 percent; Dry Unit Weight N.A. pcf. Formation generally dry.

TUNNEL DATA: 9'-11 1/2" diameter excacated; normal grade 0 percent; Ventilation system: 8" dia. pressure, 3KCFM, 5 HP @ 250' from main level. Utilities: 2" air, 1" water, 2-1 1/2" pressure and 1-3" return hydraulic lines. Water inflow: None. Power system: 110V lighting, 440V to scraper hoist. Muck Haulage: 30 HP hoist and 42" scraper to raise, all rail on main level. Personnel: rail and ladders; supplies: rail and hoist. Support: Continuous: 9'-6" dia. x 4" H sets at 45".

EXCAVATION DATA: Machine: Calweld Oscillator. Wt: 69K#. Cutters: 278 Carboloy drag bits: 258 "J" tools interior, 20 experimental gage rippers. 8 RPM; Torque 1200K#; Thrust: 300K# max., 285K# operating; no anchors; Muck pickup by flight conveyor, discharge at rear of machine, removal by scraper. Guidance by survey. Remote power unit: 2-90 gpm, 2500 psi hydraulic pumps w/125 HP motors on main level; thrust and rotation through hydraulic cyliners.



Rock Class: Metamorphic: Coarse grained, interlayered hematite and martite. Strength class N.A. RQD: 0 percent. Dry Unit Wt.: N. A. pcf.

System Class: Oscillator, Drag Cutters, Scraper/Rail Haulage.

IDENT. NUMBER MB-1

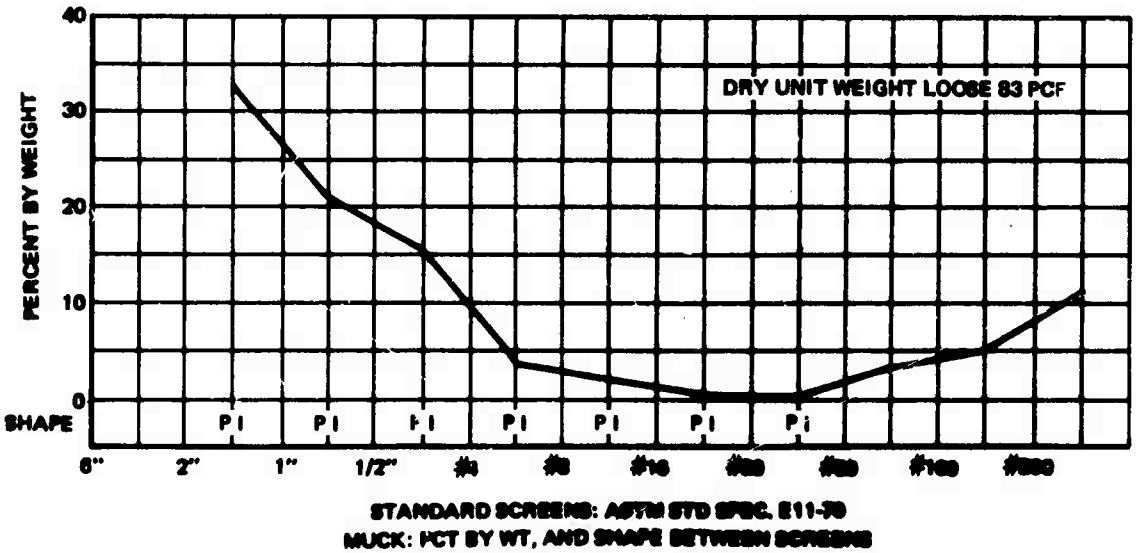
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-6

ROCK DATA: Lithology: Sedimentary: Fine grained, well compacted light brown sandstone, over 50% quartz. Uniaxial compressive strength 16.1K psi. RQD 92 percent. Dry Unit Weight: 171 pcf. Shore hardness: 61. Formation generally dry.

TUNNEL DATA: Size and shape: 18'-1" dia., round. Grade: (-) 7 percent to (+) 17 percent (0 percent where sampled). Ventilation system: 36" dia. exhaust, 17K CFM, 75 HP @ 4100'. Utility system: 2" water, 4" pump. No air line - compressor on machine. Water inflow: 5-10 gpm; Power system: 4160/480; Haulage: Muck: 36" conveyor, suspended from top; Supply and personnel: FWD Diesel. Support system: 6" x 8.2# channels x 9.5' or 13.5' @ 4' or 2', secured by 5/8" x 4' rock bolts.

EXCAVATION DATA: Machine: Robbins #131-122, Weight 260 tons; Cutters: Robbins: 47 disc: 5-12" gage, 1-7 1/2" triple center, 41-12" interior. 4 1/2 RPM; center cutter integral with head. Torque: 1200 HP input; Thrust 1,580K# max., 1,200K# operating. Muck pickup by buckets fixed to head, discharging on 36" conveyor. System includes 390' of "piggy back" conveyor supported by monorail, which advances with the TBM. Guidance by laser, Power system: Six-480V, 200 HP motors drive head through hydraulic pumps and motors.



Rock Class: Sedimentary: Fine grained, Sandstone. High Strength. 92 percent RQD. Dry Unit Wt.: 171 pcf.

System Class: Machine Excavation, Disc Cutters, Suspended Conveyor Haulage.

IDENT. NUMBER W-1

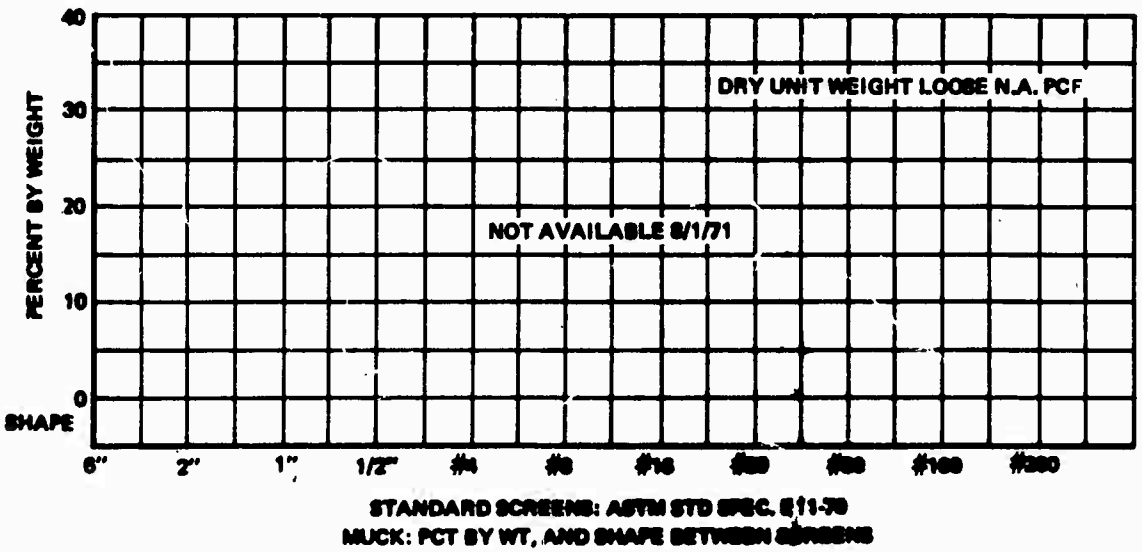
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-7

ROCK DATA: Lithology: Sedimentary: Fine grained, well compacted light brown sandstone, over 50 percent quartz. Uniaxial compressive strength 16.1K psi. RQD 92 percent. Dry Unit Weight: 171 pcf. Shore hardness: 61. Formation generally dry.

TUNNEL DATA: Size and shape: 18'-1" dia., round. Grade (-) 7% to (+) 17%. Ventilation system: 36" dia. exhaust. 17K CFM, 75 HP @ 4100'. Utility system: 2" water, 4" pump. No air line - compressor on machine. Water inflow: 5-10 gpm; Power system: 4160/480; Haulage: Muck. 36" conveyor, suspended from top; supply and personnel: FWD Diesel. Support system: 6" x 8.2# channels x 9.5' or 13.5' @ 4' or 2', secured by 5/8" x 4' rock bolts, continuous.

EXCAVATION DATA: Machine: Robbins #181-122, Weight 260 tons; Cutters; Robbins: 47 disc: 5-12" gage, 1-7 1/2" triple center, 41-12" interior. 4 1/2 RPM; center cutter integral with head. Torque: 1200 HP input; Thrust 1,580K# max., 1,200K# operating. Muck pickup by buckets fixed to head, discharging on 36" conveyor. System includes 390' of "piggy back" conveyor supported by monorail, which advances with the TBM. Guidance by laser. Power system: Six-480V, 200 HP motors drive head through hydraulic pumps and motors.



Rock Class: Sedimentary: Fine grained Sandstone, High Strength. 92 percent RQD. Dry Unit Wt.: 171 pcf.

System Class: Machine Excavation, Disc Cutters, suspended conveyor haulage.

IDENT. NUMBER W-2

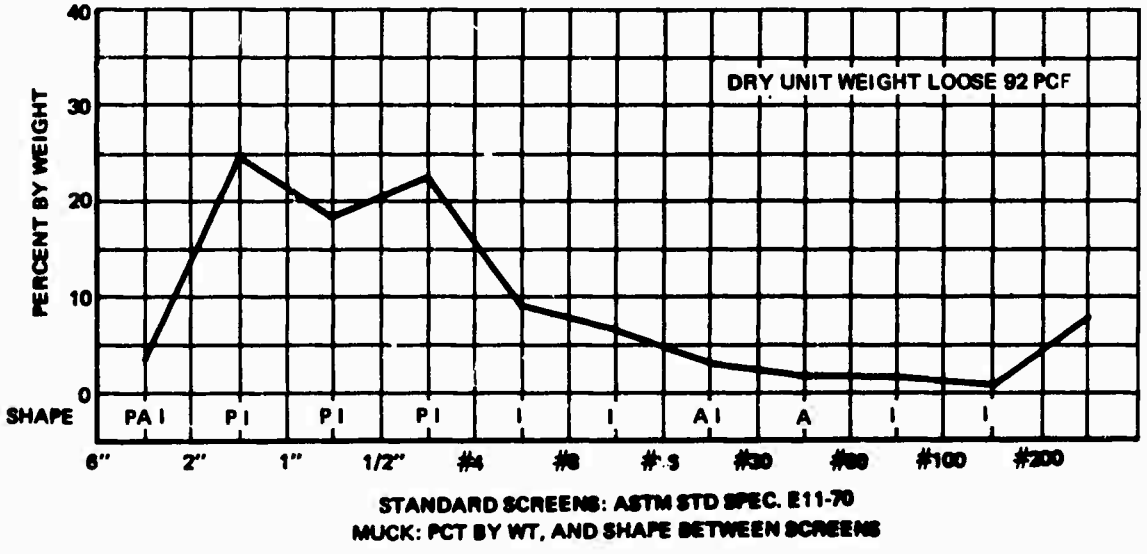
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-8

ROCK DATA: Lithology: Sedimentary light to medium gray, fine grained dolomitic limestone, some chert nodules, traces to occasional clay partings, Uniaxial Compressive Strength: 8.1K psi. Estimated RQD 100 percent. Dry Unit Weight 176 pcf. Groundwater table above tunnel, occasional seepage from minor fractures and faults.

TUNNEL DATA: Size: 13' 8" shape: round, grade (+) 1/4 percent, Ventilation system: pressure, 21K CFM, 28" pipe. Utility system: 6" air line, 2" water line, 6" pump line. Water inflow 40 to 120 gpm, Power system: 4160V/480V. Haulage system: muck, supplies, personnel, by rail cars. Support system: none.

EXCAVATION DATA: Machine: Alkirk Hardrock, total weight 400 tons, Cutters: Lawrence Mfg. Company, T.C. button tricone, and disc, total number: 28: Gage 5-15" TCB roller, Center 1-24" TCB tricone, Interior 11-15" TCB disc. 11-15" TCB roller. Rotation: Center cutter-30 RPM, Head-9 RPM. Torque center-150 HP, Head-600 HP, Total Thrust 853K lbs. Muck collection system, face to rear: buckets, 24" belt conveyor. Power system: hydraulic. Guidance system: Laser.



Rock Class: Sedimentary: Limestone. Medium Strength. RQD 100 percent. Dry Unit Wt.: 176 pcf.

System Class: Machine, TCB tricone, Rollers and Discs, Rail Haulage.

IDENT. NUMBER LAW-2

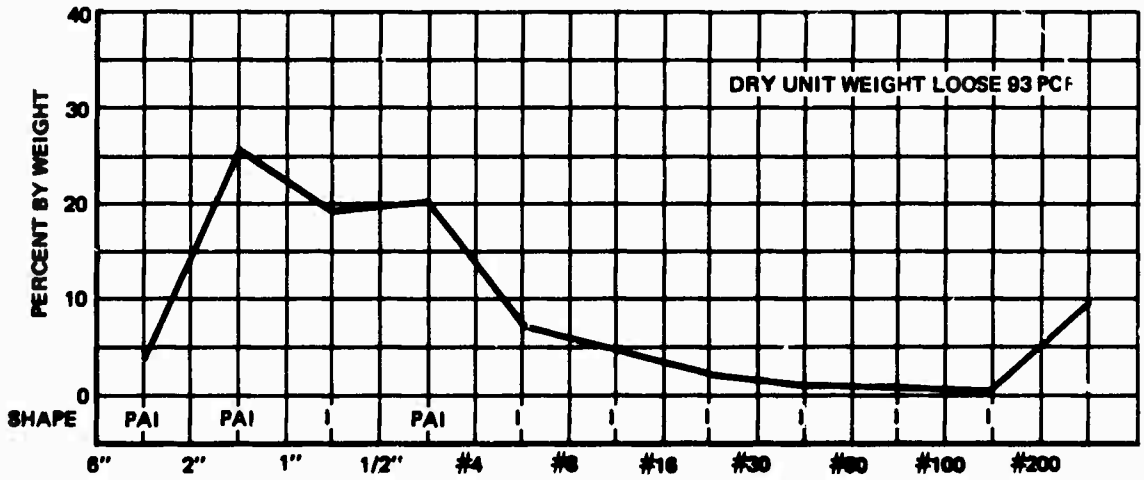
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-9

ROCK DATA: Lithology: Sedimentary light to medium gray limestone, traces to occasional clay partings, Uniaxial Compressive strength: 8.1K psi. Estimated RQD 100 percent. Dry Unit Weight 176 pcf. Groundwater table above tunnel, occasional seepage from minor fractures.

TUNNEL DATA: Size 13'8", shape: round, Grade (+) 1/4 percent, Ventilation System: 21K CFM, 28" pipe. Utility system: 6" air line, 2" water line, 6" pump line. Water inflow 40 to 120 gpm. Power System: 4160/480V. Haulage system: muck, supplies, personnel by rail. Support system: none.

EXCAVATION DATA: Machine: Alkirk Hardrock. Total weight 400 tons. Cutters: Lawrence Mfg. Company, T.C. button tricone and discs. Total number: 28: Gage 5-15" TCB roller, Center 1-24" TCB tricone, Interior 11-15" TCB disc, 11-15" TCB roller. Rotation: Center cutter-30 RPM, Head-9 RPM. Torque, Center-150 HP, Head-600 HP, Total Thrust 853K lbs. Muck Collection System face to rear: buckets, 24" belt conveyor. Power system: hydraulic. Guidance system: Laser.



Rock Class: Sedimentary: Limestone. Medium strength. RQD 100 percent. Dry Unit Wt.: 176 pcf.

System Class: Machine, TCB tricone, Rollers and Discs, Rail Haulage.

IDENT. NUMBER LAW-3

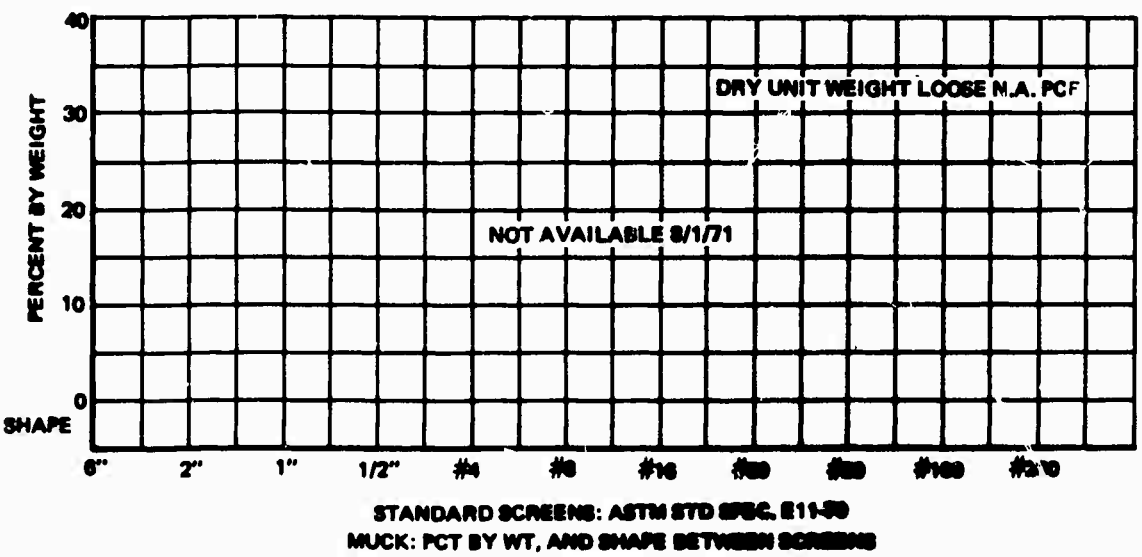
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-10

ROCK DATA: Lithology: Sedimentary light to medium gray fine grained dolomitic limestone, with occasional clay partings. Uniaxial compressive strength: 7.5K psi, Estimated RQD 100% Dry Unit Weight 176 pcf. Groundwater table above tunnel, occasional seepage from minor fractures.

TUNNEL DATA: Size: 13'8", Shape: round, Grade (+) 1/4 percent. Ventilation system: 28" pipe 21K CFM. Utility system: 6" air line, 2" water line. 6" pump line. Water inflow 40 to 120 gpm. Power system: 4160V/480V. Haulage system: muck, supplies, personnel, by rail. Support system: none.

EXCAVATION DATA: Machine: Alkirk Hardrock. Total weight 400 tons, Cutters: Lawrence Mfg. Company, T.C. button and discs. Total number: 28 Gage 5-15" TCB roller, Center 1-24" TCB tricone, Interior 11-15" TCB disc., 11-15" TCB roller. Rotation: Center cutter-30 RPM, Head-9 RPM. Torque Center-150 HP and Head-600 HP. Total Thrust 853K lbs., Muck system: buckets from face, belt, conveyor to rear. Power system: hydraulic, Guidance system: Laser.



Rock Class: Sedimentary: Limestone, Low Strength. RQD 100 percent. Dry Unit Wt.: 176 pcf.

System Class: Machine, TCB tricone, Rollers and Discs, Rail Haulage.

IDENT. NUMBER LAW-4

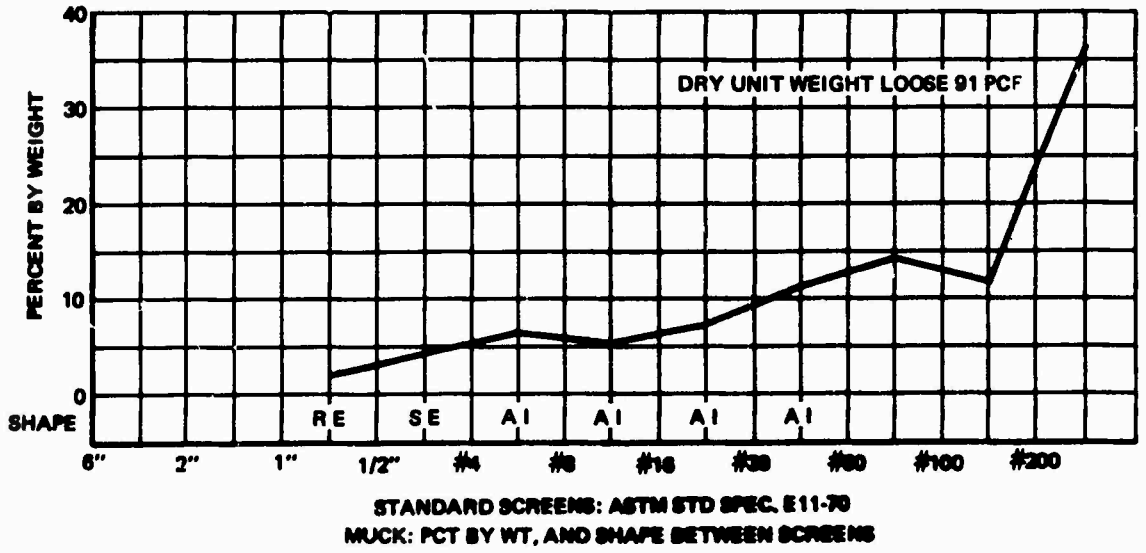
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-11

ROCK DATA: Lithology: Sedimentary arkosic sandstone, Saugus formation, irregularly bedded, loosely consolidated with layers and lenses of silty mudstone. Uniaxial Compressive Strength: less than one K psi. Estimated RQD: 0 to 35 percent. Dry Unit Weight: 113 pcf. Ground water: Saturated: water table above tunnel, heading is drained in advance by lateral pilot holes in ribs.

TUNNEL DATA: Size: 21 ft., shape round, Grade: (+) 0.2 pct. Ventilation system: 20 K cfm, 36" pipe, pressure at face, exhaust in access. Utility System: 6" air, 6" pump discharge line. Water inflow 200 gpm. Power System: 4160V/480V. Haulage system: muck, personnel, supplies by rail cars. Support System: continuous: 4' precast concrete rings 8" and 10" thick, erected in 4 segments.

EXCAVATION DATA: Shield: Robbins 221S ripper, Total weight 285T. Total Thrust 3,500 tons, Muck collection system: muck is ripped from the face by a ripper tooth and drawn through the shield to a 6" conveyor by hydraulic ram with a bucket opposite the ripper tooth. Guidance system, Laser. Power system: Hydraulic.



Rock Class: Sedimentary: Sandstone and Silty mudstone, Strength class: Very Low. RQD: 0 to 35 percent. Dry unit wt. 113 pcf.
System Class: Shield: Ripper, Bucket, to belt. Rail Haulage.

IDENT. NUMBER SF-1

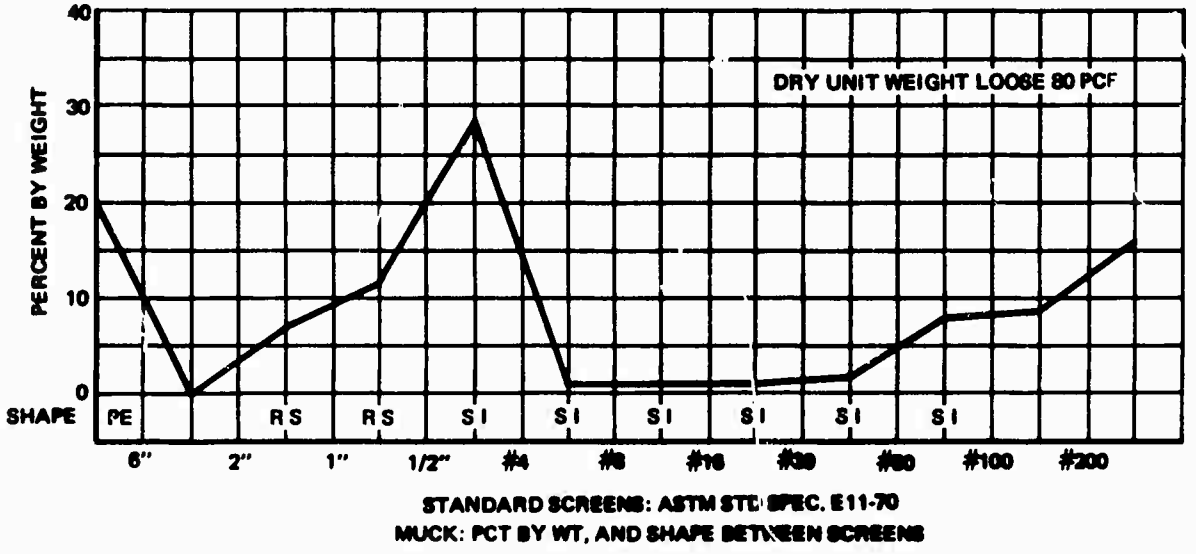
MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-12

ROCK DATA: Lithology: Sedimentary sandstone, biotite rich siltstone, Sunshine ranch formation, poorly to well consolidated, poorly to well sorted Uniaxial compressive strength 2.4 K psi. Estimated RQD 50 percent. Dry unit weight: 142 pcf. Ground water occurrence: saturated.

TUNNEL DATA: Size: 21 ft., Shape: round, Grade: (+) 0.2 pct, Ventilation system 20 Kcfm 36" pipe, pressure at face, exhaust in access. Utility system: 6" air, 6" pump discharge line. Water inflow 20 gpm. Power system: 4160V/480V. Haulage system: muck, personnel, supplies by rail cars. Support system: continuous, 4' precast concrete rings 8" and 10" thick, erected in 4 segments.

EXCAVATION DATA: Shield: Robbins 221S ripper, total wt 285T. Total thrust 3,500 tons. Muck collection system: muck is ripped from face by a ripper tooth and drawn through the shield to a 6' conveyor by hydraulic ram with a bucket opposite the ripper tooth. Guidance system: Laser, Power system: Hydraulic.



Rock Class: Sedimentary, Sandstone, Siltstone, Strength class Very Low. RQD: 50 percent Dry unit wt 142 pcf.
System Class: Shield, Ripper, Bucket to belt, Rail haulage.

IDENT. NUMBER SF-2

MDN STUDY SYSTEM DATA SHEET MDN

Figure 3-13.

4. DOD IMPLICATIONS

Other investigations have shown that the data accumulated under the program are nonexistant in usable form elsewhere. While some tunnel boring machine (TBM) manufacturers and operators consider muck size an indicator of cutter efficiency, changes are noted during informal inspections at the machine, and are seldom recorded except as showing a need for cutter replacement. A few screen analyses have been run, but results normally are not made available outside of the manufacturer's organization.

The choice of transportation systems usually is based on availability and contractor familiarity with the equipment used at other sites. In some cases, the choice has been completely unsuitable for the muck produced. This has resulted in delays and additional expense which may be avoided by using the information being collected under this program.

Previous investigations also have indicated that major modifications of conventional equipment, or design of completely new systems, will be necessary to dispose of the muck from the high speed excavation systems predicted for the future. Muck characteristic data is a requisite as a basis for the engineering design of system improvements, and should be used to indicate the areas in which research and development of new methods will be most productive.

5. IMPLICATIONS FOR FURTHER RESEARCH

The scope of the program during the first year is limited by availability of time, funds and work sites in some rock formations of major interest. The planned program provides for a third of the samples to be taken in each of the "High" and "Medium" strength rock classifications, and for the remainder to come from "Low" and "Very Low" classifications. The rock type not represented, the "Very High" strength classification, should be sampled to provide data on this upper strength range of existing formations. Lithologic classifications which are expected to be sampled under this contract will include examples of relatively coarse gained igneous rocks, three types of metamorphic rocks, and four types of sediments. To provide data on other important rocks, samples should be taken from the stratified and the finer grained igneous formations. It is probable that sampling the latter classification would also provide examples of the "Very High" strength category.

The engineering and muck properties of rocks of the same lithologic type may vary over a wide range. To make the MDN concept a useful tool in the rapid excavation program, every opportunity should be taken to obtain data from as many new sites as possible in order to confirm a previous assignment of an MDN to a rock type, or to obtain data indicating that another category is justified.

Nearly one-third of the operations sampled under the current program will be conventionally driven tunnels. While the major interest is in mechanical excavation, the most rapid progress in the stronger rocks is being made by conventional methods. Therefore, it is believed that this ratio should be maintained to provide data from high speed materials handling systems.

Provision for performing Schmidt hardness tests on rocks and abrasiveness tests on muck is also recommended as a part of continuing research, to provide data which may be highly significant, but which is beyond the scope of the current program.

Statistically, the reliability of data and conclusions is a function of the sampling frequency. For this reason, at least three specimens of the same rock have been tested whenever possible to provide engineering property information. However, current funding will permit taking additional samples to improve the confidence level of about one-third of the muck data. Since nearly two-thirds of the sites sampled in 1971 will be available in the following year, resampling muck from these operations is recommended.

6. SPECIAL COMMENTS

No equipment has been purchased or developed, nor has any invention been made in the course of the work performed under this contract.

GLOSSARY

ASTM	American Society for Testing and Materials.
BM	Beam
CFM	Cubic feet per minute
COMPR.	Compressed
CONTIN.	Continued
CY	Cubic Yard
DEG.	Degrees
DIA.	Diameter
FWD	Four Wheel Drive
GPM	Gallons per Minute
HP	Horse Power
HRS.	Hours
IN.	Inch
Inter.	Internal
K	Thousand
LBS	Pounds
MDN	Muck Designation Number
Moist.	Moisture
MM	Millimeter
NA.	Not Available
NO.	Number
PCF	Pounds per Cubic Foot
PCT	Percent
PMSRC	Pittsburgh Mining and Safety Research Center
POT.	Potential
PSI	Pounds per square inch
REG.	Regular
RPM	Revolutions per Minute
RQD	Rock Quality Designation
SPECIF.	Specific
STRNTH.	Strength
TBM	Tunnel Boring Machine
TCB	Tungsten Carbide Button
T.	Ton
V	Volt
VOL	Volume
W/	With
WT.	Weight
'	Foot
"	Inch
#	Number
%	Percent
(+)	Plus
(-)	Minus

Rock Strength

Very High	+32000 psi
High	1600 to 32000 psi
Medium	8000 to 16000 psi
Low	4000 to 8000 psi
Very Low	0 to 4000 psi

APPENDIX A

TUNNEL LIST

TUNNEL PROJECTS

Compiled by Holmes & Narver, Inc., Anaheim, California, under U. S. Bureau of Mines, Contract HO210013. Revised 1 August 1971

NORTH AMERICAN CONTINENT

PROJECT & LOCATION	OWNER OR AGENCY	SIZE	LENGTH	CONTRAC
MINERAL CREEK DIVERSION TUNNEL Ray, Arizona	Kennecott Copper Corporation Ray Mines Div. Hayden, Arizona	16'x16' Excav. 15'x15' Lined	3.6 Miles	Fluor-Uta Engrg & C Company

Excavation by conventional methods. Formations include 14 rock classifications, predominantly quartzite, shale, diabase, schist, altered granite, porphyry and dacite. Core specimens exist, but owner management has not approved core testing or muck sampling. The operation is now suspended pending contract re-negotiation.

LAKESHORE MINE Casa Grande, Arizona	Hecla Mining Company- El Paso Natural Gas	14'x14' 14'x18' plus level development	7500' 7500'	Hecla Min Co. -own f

The two 7500' headings are declines at a minus 15°, currently at 5900' slope distance from the portal. Levels are being developed at 1000' and 1400' vertically below the portal. Formations encountered include quartz diorite and quartz monzonite porphyry. Some rock data is reported available from a shaft boring machine manufacturer who is scheduled to begin a 12' diameter ventilation shaft from surface to the upper development level in September, 1971.

SAN FERNANDO WATER TUNNEL Sylmar-Pacoima, California	Metro. Water District of Southern California	21' Dia.	5-1/2 Miles	Lockheed building a Construct

A Robbins boring machine was used as a shield through which muck was drawn, as a mucker, and as ground support during liner erection. Penetrated formations are wet and dry sand, silt, and pebble to cobble gravel, poorly and well consolidated siltstone, sandstone and conglomerates. Cores and muck samples from the Saugus and Sunshine Ranch formations have been collected and tested. This site is closed indefinitely because of an explosion in the tunnel on June 24, 1971.

TUNNEL PROJECTS (Continued)

PROJECT & LOCATION	OWNER OR AGENCY	SIZE	LENGTH	CONTRACTOR
CLIMAX MINE Leadville (Climax) Colorado	American Metal Climax, Inc. (AMAX)	13' Dia.	Several @ 1200' to 1500'	Calweld (Santa Fe Springs, C leased to AMA

The machine was operated on a non-priority basis while necessary modifications are made to bore 35,000 to 40,000 psi graniticgniess formations. Operation was initiated in April, 1971, in another location in the mine, and terminated in May, 1971. Core tests and sieve, moisture, and unit weight tests on muck samples have been completed. No further site work is possible: the machine has been removed from the site.

NAST TUNNEL Fryingpan Project Merideth, Colorado	U.S. Bureau of Reclamation Denver, Colorado	10' Dia.	3 Miles	Peter Kiewit Sons Company

A Wirth boring machine is operating in a competent section of the tunnel, has been modified by installation of shields necessary for operation in highly sheared ground Formations penetrated are predominantly granite, granite gneiss, granite porphyry, and granodiorite with compressive strengths from 18,000 psi to 24,300 psi. Rock is highly sheared in zones from a few feet to 400' thick. Rock and muck samples have been collected and tests performed.

GRANITE ADIT Fryingpan Project Merideth, Colorado	U.S. Bureau of Reclamation Denver, Colorado	9'x9'	700'	Peter Kiewit Sons Company

An adit to the Nast tunnel, the heading has started as a conventional operation in badly fractured granite, and is expected to reach competent rock.

HUNTER TUNNEL Fryingpan Project Merideth, Colorado	U.S. Bureau of Reclamation Denver, Colorado	10'x10'	4.4 Miles	Granite Construction Company

A conventional operation in formations similar to the Nast tunnel. Lithologic and Engineering property data has been collected from the U.S. Bureau of Reclamation. Initial rock and muck samples have been collected and tests performed.

TUNNEL PROJECTS (Continued)

PROJECT & LOCATION	OWNER OR AGENCY	SIZE	LENGTH	CONTRACT
ROCKVILLE TUNNEL Section 4a Washington, D. C.	Washington Metropolitan Area Transit Authority (W. M. A. T. A.) Washington, D. C.	16'-6" Nominal Finished Diameter	3,000'	S. A. Healy

Conventional tunnel in micaceous schist and gneiss, reported compressive strength 8,000-18,000 psi. Lithologic and Engineering property data has been collected from the W. M. A. T. A.

FOGGY BOTTOM-ROSSLYN TUNNEL Section C-4 Washington, D. C.	W. M. A. T. A. Washington, D. C.	16'-8" Dia. Finished	4,000' each of two bores	S & M Constructo (E. W. Mur

To be driven in gneiss under the Potomac River. The schistose rock structure is reported to result in high shear strength and low compressive strength. The formation is expected to bore like a 25,000 psi granite. Lithologic and Engineering property data has been collected from the W. M. A. T. A. Recent reports indicate excavation will be by conventional methods.

LAWRENCE AVE. SEWER Chicago, Illinois	Dept of Public Works, Bureau of Engineering, City of Chicago, Ill.	13'-8" Diameter	4.8 Miles	McHugh Constructio Company

A Lawrence boring machine is operating in limestone. Collected logs of 13 drill holes show lithology, compressive strength (7,000-35,000 psi), core recovery, and hydrologic test results. The tunnel is scheduled for completion in September, 1971. Rock and muck samples have been collected, and muck tests performed.

WHITE PINE COPPER CO. White Pine, Michigan	Copper Range Company, New York, New York	18'-1" Diameter	See below	Tunneling b White Pine with own force

A Robbins machine has been operating in sandstone since 1969, will complete a connecting drift into existing workings and be moved to another location in the mine. An Atlas-Copco machine is being modified for a trial in the ore, which is a hard shale. Normal drifting

TUNNEL PROJECTS (Continued)

PROJECT & LOCATION	OWNER OR AGENCY	SIZE	LENGTH	CONTRACTOR
WHITE PINE COPPER CO. (Continued)				

is conventional. Collected rock property data includes compression, Brazilian tensile, and Shore hardness test results on the sandstone, which varies from 13,000 to 22,000 psi in compression. Rock and muck samples from the Robbins machine have been collected and tested. Future plans include a trial of the Robbins machine in a shale horizon.

MATHER MINE Negaunee, Mich.	Cleveland Cliffs Iron Mining Co.	9'-9" Dia.	200' Cross Cuts	Own force w/leased Calweld TBM

An Oscillator machine with ripper cutters has been used to drive 200' crosscuts in a hematite-martite formation, from which rock and muck samples have been collected.

NEVADA TEST SITE Mercury, Nevada	U.S.A.E.C. and Defense Atomic Support Agency (DASA) Mercury, Nevada	Various, see below	Various, see below	Reynolds Electrical & Engineering Co

Two tunnels are operating, a 13'x13' modified horseshoe section about 2,000' long, and a 30'x30' modified horseshoe section which will be reduced to a smaller section about 1,000' long. Normal tunneling is conventional. An Alpine Miner, described as an articulated head ripper, has been in use on an initial trial basis and may provide an opportunity for comparison of the muck produced by the two systems. Formations are volcanic tuffs which vary from 600 to 4,500 psi in unconfined compressive strength. Engineering property data has been collected by the U.S. Geological Survey and by DASA.

NAVAJO IRRIGATION PROJECT Farmington, New Mexico	U.S. Bureau of Reclamation Denver, Colo.	20.5' Dia.	3 miles	Fluor-Utah Engrg & Const Company

A Dresser boring machine is being assembled to operate in sandstones with unconfined compressive strengths of 800 to 9700 psi and siltstones with unconfined compressive strengths of 1500 to 2100 psi.

TUNNEL PROJECTS (Continued)

PROJECT & LOCATION	OWNER OR AGENCY	SIZE	LENGTH	CONTRACT
QUEEN LANE CONDUIT Philadelphia, Pa.	City of Philadelphia	11' Dia.	7000'	S & M Constructor

A Jarva machine is driving the last 2000' of tunnel in mica schist, reported as 6000 to 25,000 psi in compressive strength. The project is scheduled for completion in August, 1971. Rock and muck samples have been collected for testing.

CURRANT & LAYOUT TUNNELS Strawberry Aqueduct, Heber City, Utah	U.S. Bureau of Reclamation Denver, Colorado	10'-4" Dia.	Combined Length 4.9 miles	S.A. Healy

A Robbins boring machine is being assembled to operate in shale, conglomerate and sandstone. Collected logs of 13 drill holes show lighology. Compressive strength test results, varying from 5,000 psi for a shale to over 38,000 psi in the conglomerate, have been provided by the Bureau of Reclamation.

CONTR. 817 & 843 SEWER TUNNELS Milwaukee, Wisc.	City of Milwaukee	11'-2" Dia.	4000'	W. J. Lazyn Company

A Jarva boring machine is being assembled for operation in limestone. Engineering data is reportedly available from the City of Milwaukee.

JEFFREY CITY URANIUM MINE Jeffrey City, Wyo.	Western Nuclear, Inc.	10'x10'	600' Devel. Drifts	Owner Operated

An Alpine miner and a Serpentix conveyor are driving mining headings in soft sandstone, described as less than 1000 psi compressive strength.

NEW YORK CITY, N.Y., Contract #13	Dept/Public Works, NYC	11' Dia	9200'	Perini-B & G.H. Ball-S Constructor

Scheduled to start in December, 1971, using the Jarva boring machine released from the Philadelphia Water Conduit project. Formation is mica schist; compressive strength 15,000 to 30,000 psi. Cores and rock test data are reported to be available from the owner.

TUNNEL PROJECTS

Compiled by Holmes & Narver, Inc., Anaheim, California, under U. S. Bureau of Mines, Contract HO210013. Revised 1 August 1971

LOCATIONS OUTSIDE THE NORTH AMERICAN CONTINENT

PROJECT & LOCATION	OWNER OR AGENCY	SIZE	LENGTH	CONTRACT
SEIKAN INTER-ISLAND TUNNEL Hokkaido to Honshu-Japan	Ministry of Transportation Japanese Government	See below	30 + KM	Unknown

This tunnel site has been under investigation for many years. A Habegger boring machine is reported driving a pilot tunnel, probably less than 10' in diameter, from the Hokkaido terminus in soft formations. A conventional tunnel of similar size is reported advancing in intruded igneous rock from the Honshu side. Voluminous Engineering data is said to have been collected.

COOKHOUSE TUNNEL Orange-Fish-Sundays Project South Africa	South African Board of Water Affairs, Summerset East, South Africa	16'-6" Diameter	8 miles	Agency's own force

A Lawrence boring machine, owned by the agency, has been operating in limestone and sandstone reported to run from 24,000 to 47,000 psi in unconfined compression. Lithologic and Engineering property data may be available from the agency.

PIPE HEAD-POTTSHILL PIPELINE New South Wales Australia	Metropolitan Water, Sewage, & Drainage Board Sidney, New South Wales, Australia	13' Dia bored 10' Finished Diameter	4.9 miles	Unknown

A report giving geology, lithology and engineering properties is available from the agency.

APPENDIX B

RAW DATA SHEETS

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY	COMPR	RQD	.....HARDNESS.....		
MAI	MAST	IONEOUS: GRAY MEDIUM	WT	STRNTH	PCT	SHORE	MOH	SCHMIDT
	SAMPLE NO	TO FINE GRAINED GRANITE	PCF	KPSI				
	MAST-I	MODERATELY TO SLIGHTLY	167	18.0	90	NA	NA	NA
		FRACTURED AND JOINTED						
		18 TO 20 PCT QUARTZ						
		50 TO 60 PCT FELDSPAR						
		BALANCE DARK MINERALS						

ROCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	.....PER CENT BY WEIGHT BETWEEN SCREENS..... 6IN–3IN	3IN–1IN	1IN–1/2	1/2–NO4	NO4–NO8	NO8–NO16	NO16–NO30	NO30–NO50	NO50–NO100	NO100–NO200	PCT (-) NO200
80	9.36	0.0	0.0	0.0	2.2	14.9	12.8	12.4	12.3	0.6	11.8	6.8	18.5

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

					PI	AI	AI	AI	AI	SI	S	

.....PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH.....

.297	.210	.105	.005	.063	.040	.0395	.0250	.0103	.0140	.0095	.0066	.0050	.0034

PCT VOL CHANGE (+).065 IN SIZE	.....ATTERBERG LIMITS..... LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

.....MATERIAL SIZE (-).105 IN..... SPECIF GRAVITY	ANGLE/REPOSE 1 IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ 1/71

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT	COMPR STRNTH	RQD	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
NA2	NAST	IGNEOUS: GRAY MEDIUM						
	SAMPLE NO	TO FINE GRAINED GRANITE	PCF	KPSI				
	NAST-2	MODERATELY TO SLIGHTLY	167	18.0	90	NA	NA	NA
		FRACTURED AND JOINTED						
		10 TO 20 PCT QUARTZ						
		50 TO 60 PCT FELDSPAR						
		BALANCE DARK MINERALS						

BULK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 3IN	2IN	1IN	1/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

					PI	PI	PI	AI	AI	SI	SI	S	

PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH

.297	.210	.105	.085	.063	.048	.0355	.0250	.0183	.0140	.0095	.0066	.0050	.0034

POT VOL CHANGE (-).065 IN SIZE	ATTERBERG LIMITS LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

MATERIAL SIZE (-).185 IN SPECIF GRAVITY	ANGLE/REPOSE 1 IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ 1/71

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY	COMPR	RQD	.....HARDNESS.....		
MUI	HUNTER	IGNEOUS: FINE GRAINED	WT	STRNTH	PCT	SHORE	MOH	SCHMIDT
	SAMPLE NO	MODERATELY JOINTED GRAY	PCF	KPSI				
	M-I	GRANITE WITH 1.5 TO 2 FT			00	NA	NA	NA
		BANDS OF LIGHT TAN						
		PEGMATITE AND LAMINATED						
		GRANITIC GNEISS						

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	*.....PER CENT BY WEIGHT BETWEEN SCREENS.....* 6IN	2IN	IIN	1/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

*.....PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH												.....*
.297	.210	.105	.085	.063	.048	.0355	.0250	.0103	.0140	.0095	.0066	.0050	.0034

POT VOL CHANGE (-).065 IN SIZE	*.....ATTERBERG LIMITS..... LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

.....MATERIAL SIZE (-).105 IN..... SPECIF GRAVITY	ANGLE/REPOSE I IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ 1/71

KEY	IDENTIFICATION	ROCK PROPERTIES						
CLI	CLIMAX	METAMORPHIC: HIGHLY	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
	SAMPLE NO	METAMORPHOSED GRANITIC						
	CL-1	GNEISS HIGHLY SILICIFIED	174	[illegible]	10	NA	NA	NA
		MODERATELY TO HIGHLY						
		FRACTURED						

MUCK DATA

DRY WT	UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN	2IN	IIN	1/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
87		0.8	0.0	0.0	0.0	4.8	37.0	10.1	11.2	8.5	6.8	5.6	5.4		I.8

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

					AI	AI	AI	AI	AI	AI	AI		

PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH

.297	.210	.105	.085	.063	.048	.0355	.0250	.0183	.0140	.0095	.0066	.0050	.0034

PCT VOL CHANGE (-).068 IN SIZE	ATTERBERG LIMITS LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

MATERIAL SIZE (-).105 IN SPECIF GRAVITY	ANGLE/REPOSE I IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ 1/71

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
GUI	QUEEN LANE	METAMORPHIC: GRAY MICA						
	SAMPLE NO	SCHIST, OCCASIONAL						
	GL-I	QUARTZ SEAMS, MICA VARIES			38	NA	NA	NA
		FROM DENSE FINE GRAINED						
		TO EXTREMELY COURSE						

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(-)6 IN SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN	2IN	IIN	I/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH

.297	.210	.105	.065	.063	.048	.0395	.0250	.0103	.0140	.0095	.0066	.0050	.0034

PCT VOL CHANGE (+).065 IN SIZE	ATTERBERG LIMITS LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

MATERIAL SIZE (-).105 IN

SPECIF GRAVITY	ANGLE/REPOSE I IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANG 2 INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ I/71

KEY	IDENTIFICATION	ROCK PROPERTIES						
MB1	MATHER-B	METAMORPHIC: INTERLAYERED	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT	.....HARDNESS..... SHORE	MOH	SCHMIDT
	SAMPLE NO	BANDS OF HEMATITE AND						
	MB-1	MARTITE, HIGHLY JOINTED			0	NA	NA	NA
		NORMALLY FLAT LYING,OFTEN						
		HIGHLY FOLDED, NATURAL						
		IRON 60 PCT(+), MOISTURE						
		9 PCT , SILICA 5.5 PCT						

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	*.....PER CENT BY WEIGHT BETWEEN SCREENS.....* 6IN	2IN	IIN	I/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

*.....PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH ..... .297	.210	.105	.085	.063	.048	.0355	.0250	.0103	.0140	.0095	.0066	.0050	.0034

POT VOL CHANGE (+).065 IN SIZE	*.....ATTERBERG LIMITS..... LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

.....MATERIAL SIZE (-).185 MM..... SPECIF GRAVITY	ANGLE/REPOSE 1 IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ 1/71

KEY MI	IDENTIFICATION 5-12	ROCK PROPERTIES SEDIMENTARY: FINE GRAINED	DRY WT PCF	COMPR STRNTH KPSI	ROD PCT	HARDNESS SHORE	MOH	SCHMIDT
	SAMPLE NO	WELL COMPACTED LIGHT						
	W-1	BROWN SANDSTONE	171	16.1	92	61	NA	NA
		OVER 50 PCT QUARTZ						

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN	2IN	1IN	1/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
88	5.35	0.0	0.0	33.8	20.9	15.5	4.4	2.7	1.3	1.1	3.8	5.0		11.8

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

	PI	PI	PI	PI	PI	PI	PI

PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH

.297	.210	.105	.085	.063	.048	.0355	.0250	.0103	.0140	.0095	.0066	.0050	.0034

POT VOL CHANGE (+).065 IN SIZE	ATTERBERG LIMITS LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

SPECIF GRAVITY	MATERIAL SIZE (-).185 IN. ANGLE/REPOSE 1 IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/. 1/71

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY	COMPR	RQD	.....HARDNESS.....		
W2	7-22	SEDIMENTARY: FINE GRAINED	WT	STRNTH	PCT	SHORE	MOH	SCHMIDT
	SAMPLE NO	WELL COMPACTED, LIGHT	PCF	KPSI				
	W-2	BROWN SANDSTONE	171	16.1	92	61	NA	NA
		OVER 50 PCT QUARTZ						

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	*.....PER CENT BY WEIGHT BETWEEN SCREENS.....*									PCT (-)
			6IN	2IN	1IN	1/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	NO200

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

.....PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH.....

.297	.210	.105	.085	.063	.040	.0355	.0250	.0183	.0140	.0095	.0066	.0050	.0034

POT VOL CHANGE (-).065 IN SIZE	*.....ATTERBERG LIMITS.....*					
	LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCF	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

..........MATERIAL SIZE (-).185 IN.....*						
SPECIF GRAVITY	ANGLE/REPOSE I IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE LATER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ 1/71

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT	COMPR STRNTH	ROD	HARDNESS		
LA2	LAWRENCE	SEDIMENTARY: LIGHT TO						
	SAMPLE NO	MEDIUM GRAY FINE GRAINED	PCF	KPSI	PCT	SHORE	MOH.	SCHMIDT
	LAV-2	DOLOMITIC LIMESTONE SOME	176	0.1	100	NA	NA	NA
		CHERT NODULES TRACES TO						
		OCCASIONAL CLAY PARTINGS						

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN	2IN	IIN	I/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
92	7.24	0.0	3.0	25.0	18.0	22.1	9.4	6.5	3.5	2.0	1.8	0.8		7.9

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

AI	PI	PI	PI	I	I	AI	A	I	I	

PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH

.297	.210	.105	.065	.063	.048	.0355	.0250	.0183	.0149	.0095	.0066	.0050	.0034

PCT VOL CHANGE (-).065 IN SIZE	ATTERBERG LIMITS LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

MATERIAL SIZE (-).185 IN. SPECIF GRAVITY	ANGLE/REPOSE I IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ 1/71

KEY	IDENTIFICATION	ROCK PROPERTIES						
LA3	LAWRENCE	SEDIMENTARY: MEDIUM TO	DRY WT PCF	COMPR STRNTH KPSI	RQD PCT	.....HARDNESS..... SHORE	MOH	SCHMIDT
	SAMPLE NO	LIGHT GRAY LIMESTONE						
	LAW-3	OCCASIONAL CLAY PARTINGS	176	8.1	100	NA	NA	NA

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	.....PER CENT BY WEIGHT BETWEEN SCREENS..... 6IN–2IN	2IN–1IN	1IN–1/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
98	5.54	0.0	4.3	25.9	19.5	20.0	7.4	5.0	3.5	1.8	1.3	1.1	9.8

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

	PAI	PAI	I	PAI	I	I	I	I	I	I

.....PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH.....

.297	.210	.105	.085	.063	.048	.0355	.0250	.0183	.0140	.0095	.0066	.0050	.0034

POT VOL CHANGE (+).868 IN SIZE	.....ATTERBERG LIMITS..... LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

.....MATERIAL SIZE (-).185 IN..... SPECIF GRAVITY	ANGLE/REPOSE 1 IN DROP	ANGLE/REPOSE 18 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ 1/71

KEY	IDENTIFICATION	ROCK PROPERTIES		DRY WT PCF	COMPR STRNTH KPSI	RQD PCT	HARDNESS SHORE	HARDNESS MOH	HARDNESS SCHMIDT
LA4	LAWRENCE	SEDIMENTARY:	LIGHT TO						
	SAMPLE NO	MEDIUM GRAY FINE GRAINED							
	LAW-4	DOLOMITIC LINESTONE		176	7.5	100	NA	NA	NA
		OCCASIONAL CLAY PARTINGS							

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN	2IN	1IN	1/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH												
.297	.210	.105	.085	.063	.040	.0355	.0250	.0103	.0140	.0095	.0066	.0050	.0034

PCT VOL CHANGE (-).065 IN SIZE	ATTENBERG LIMITS LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

MATERIAL SIZE (-).185 IN SPECIF GRAVITY	ANGLE/REPOSE I IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ 1/71

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT	COMPR STRNTH	RQD	HARDNESS		
SFI	SAN FERNANDO	SEDIMENTARY: SAUGUS				SHORE	MOH	SCHMIDT
	SAMPLE NO	FORMATION IRREGULARLY	PCF	KPSI	PCT			
	SF-1	BEDDED, LOOSELY	113	LESS	0	NA	NA	NA
		CONSOLODATED ARKOSIC SAND		THAN	TO			
		STONE WITH LAYERS AND		1.0	35			
		LENSES OF SILTY MUDSTONE						

MUCK DATA

DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN	2IN	1IN	1/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
91	18.50	0.0	0.0	0.0	2.17	4.50	6.08	5.10	7.05	11.52	14.40	12.75		36.42

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

			RE	SE	AI	AI	AI	AI

PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH

.297	.210	.149	.088	.063	.048	.0355	.0250	.0183	.0140	.0095	.0066	.0050	.0034
66.07	61.15	48.25	45.39	36.51	32.07	26.14	20.51	15.78	12.07	10.15	7.63	5.70	4.96

POT VOL CHANGE (-).065 IN SIZE	ATTERBERG LIMITS: LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX
0.0	17.75	16.19	13.94	1.56	5.8	0.27

SPECIF GRAVITY	MATERIAL SIZE (-).185 IN. ANGLE/REPOSE 1 IN DROP	ANGLE/REPOSE 10 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS
2.66	38 DEG.	33 DEG.	36 DEG.	42 DEG.	13 TO 17	NA

CURRENT ON: 8/ 1/71

KEY	IDENTIFICATION	ROCK PROPERTIES	DRY WT	COMPR STRNTH	RQD	HARDNESS		
SF2	SAN FERNANDO	SEDIMENTARY: SUNSHINE						
	SAMPLE NO	RANCH FORMATION: BLUE	PCF	KPSI	PCT	SHORE	MOH	SCHMIDT
	SF-2	GRAY BIOTITE RICH SILT-	142	2.4	50	NA	NA	NA
		STONE AND SANDSTONE						
		FRACTIONS WELL SORTED						

MUCK DATA DRY UNIT WT PCF	MOISTURE PCT	PCT(+)6 IN SIZE	PER CENT BY WEIGHT BETWEEN SCREENS 6IN	2IN	IIN	I/2	NO4	NO8	NO16	NO30	NO50	NO100	NO200	PCT (-) NO200
88	17.5	20.0	0.0	6.9	II.5	2T.4	0.4	0.5	0.6	I.2	7.6	8.5		15,2

SHAPE OF FRACTIONS BETWEEN SCREEN SIZES A=ANGULAR S=SUBANGULAR R=ROUNDED P=PLATY C=CUBIC I=IRREGULAR E=ELONGATED SP=SPHEROID

	PE	-	AS	RS	SI	SI	SI	SI	SI	SI	-

PERCENT BY WEIGHT FINER THAN PARTICLE SIZE IN MM OF FRACTION BELOW 4 MESH

.297	.2I0	.I05	.085	.063	.048	.0395	.0250	.0I03	.0I40	.0095	.0066	.0050	.0034

POT VOL CHANGE (-).046 IN SIZE	ATTERBERG LIMITS LIQUID LIMITS PCT	PLASTIC LIMIT PCT	SHRINKAGE LIMIT PCT	PLASTICITY LIMIT PCT	FLOW INDEX	TOUGHNESS INDEX

MATERIAL SIZE (-).I05 IN SPECIF GRAVITY	ANGLE/REPOSE 1 IN DROP	ANGLE/REPOSE I0 IN DROP	ANGLE/SLIDE STEEL PLATE	ANGLE INTER FRICTION	MOIST PCT	ABRASIVENESS

CURRENT ON: 8/ I/71